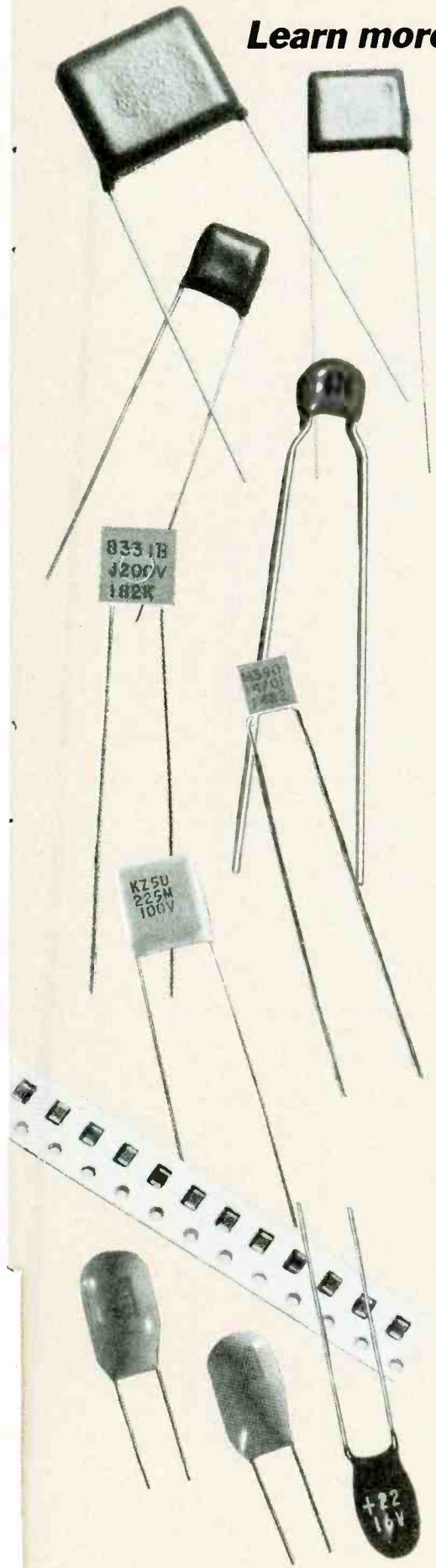

Learn more about capacitors—how they are made, and how you can apply them more cost-effectively in your circuits

CAPACITORS

RAY MARSTON

CAPACITORS RANK NEXT TO RESISTORS as the most widely purchased electronic components. Fixed and variable capacitors for electronics available from commercial sources have capacitance values from a few picofarads (pF) to farads (F). And these components are made from an amazingly wide variety of materials.

The outstanding trend in capacitor design and manufacture over the past 85 years—particularly since the arrival of the integrated circuit—has been miniaturization. The objective of all efforts has been to cram as much capacitance as possible into ever smaller packages, while at the same time increasing their reliability.

To gain a better understanding of this trend, and to appreciate what has been accomplished, it is worth reviewing the fundamental capacitor formulas. The ability of a capacitor to store electric energy is a function of its geometry and the physical characteristics of its dielectric.

The amount of energy that a capacitor can store is given by the equation:

$Q = CE$

where Q = the magnitude of the stored charge in coulombs
C = capacitance in farads
V = applied voltage in volts

Figure 1-*a* shows the simplest capacitor and identifies its principal parts and physical variables; Fig. 1-*b* is the accepted schematic symbol in North America for a fixed capacitor, and Fig. 1-*c* is the accepted symbol for a variable capacitor.

Capacitance in farads is determined by:

$C = kA/d$

where k is the dielectric constant (permitivity), the ratio of the ability of a dielectric material to store electrostatic energy to that stored by a vacuum between the same electrodes (see Table 1).
A = directly opposing plate area
d = distance between the plates

Different multiplying factors can be applied to this equation so that the value for C is in microfarads or picofarads when A and d are measured either in inches or millimeters. Nevertheless, important engineering tradeoffs can be seen from both of these equations:

- To store a given charge, more voltage is needed for a small capacitor than a large one.
- If the opposing plate area, A, is held constant, the value of capacitance can be increased by:

a. Decreasing the thickness of the dielectric, h.
b. Using a dielectric with a higher constant, k.
c. Doing both (a) and (b) simultaneously.

While not apparent from the formulas, other facts about capacitors to be considered are:

- The maximum voltage that can be impressed across a capacitor, without destroying it, depends on the dielectric and the separation of the plates.
- For a given dielectric, the allowable maximum voltage can be increased as the distance be-

www.americanradiohistory.com

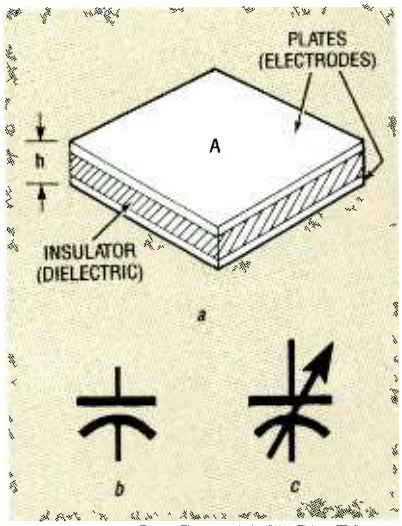

FIG. 1—A BASIC PARALLEL-PLATE capacitor has parallel metal plates or electrodes separated by a dielectric that can be air or a solid insulator.

tween the plates is increased.

The volumetric efficiency of capacitors has been improved within the constraints mentioned. How this has been done will be explained in the discussion of each of the most common capacitor manufacturing technologies.

Advanced circuit manufacturing methods have increased demand for miniature chip capacitors for hybrid circuits and surface mounting. New plastic film and ceramic dielectrics now offer a wider range of operating characteristics than was available ten years ago; metalizing has reduced capacitor weight and size by eliminating metal foil from many film capacitors now being produced.

The quality and reliability of electrolytic capacitors has been improved with more effective methods for etching foils, the introduction of better electrolytes, and improved sealing. Solid-electrolyte tantalum capacitors made as dipped radial or chip units are becoming more popular. Capacitors made from mica and glass have faded away to become specialty items, with their former functions largely performed by multilayer ceramic capacitors. Moreover, ceramic disk caps are rarely specified in new designs; they have been replaced by smaller, easier-to-place ceramic tubular capacitors.

The fabrication of increasing numbers of capacitors within very large scale integrated circuits such as microprocessors and digital signal processors has not reduced sales of discrete capacitors; in fact, the sales of certain kinds of capacitors have increased because of the proliferation of IC's. Moreover, capacitors are necessary in the external circuitry for the dedication of such multifunction linear IC's as compandor and modulation chips. Thin- and thick-film capacitors are being formed on ceramic substrates for networks and hybrid circuits that operate well into the microwave band.

Variable capacitors, still used primarily in radio-frequency circuits, are also being made from improved plastics and ceramics, a departure from their traditional dielectrics of air, glass, and ceramic, to reduce their size, extend their capacitance range, and cut cost.

Capacitor terms

Capacitors are widely specified with a glossary of widely accepted technical terms. A knowledge of these terms will be helpful to anyone who specifies or uses capacitors.

Capacitance. The basic unit for capacitance is the farad, but most capacitors for electronics applications need capacitance values that are only small fractions of a farad: microfarad (μF—one-millionth of a farad) and picofarad (pF—one-millionth of one-millionth of a farad).

Ambient temperature. The actual value of a capacitor depends on the temperature of its environment, known as *ambient* temperature. *Percent capacitance change*, a function of temperature, is referred to room temperature, 25°C.

TABLE 1
DIELECTRIC CONSTANTS COMMON CAPACITOR MATERIALS

Dielectric	*k*
Vacuum	1
Air	1.0006
Polystyrene	2.5
Polyester	3
Mica	5
Aluminum oxide	7
Tantalum oxide	25
Ceramic (low *k*)	10
Ceramic (high *k*)	100—10,000

Capacitive tolerance is the variation in capacitance value of the capacitor expressed as a percentage of its value at room temperature, 25°C, which is referred to as the *nominal value*.

Temperature coefficient (TC) is the change in a capacitor's capacitance per degree change in temperature, expressed in parts per million per degree Celsius (ppm/°C). The coefficient can be positive, negative, or zero. The letter P indicates that the coefficient is positive: N if negative. The designation NPO identifies a zero-temperature coefficient.

Rated working voltage is the maximum permissible operating voltage at which a capacitor can be continuously operated at maximum rated voltage (without derating). This rating must be specified as AC or DC because they are not usually equal.

Surge voltage is the maximum instantaneous voltage to which the capacitor should be subjected; exceeding that voltage will cause the capacitor's breakdown. Surge voltage is higher than working voltage.

DC leakage is the small amount of direct current that flows in a capacitor at a specified voltage. Caused by the presence of free charge carriers within the dielectric, it is the reason why a charge cannot be stored indefinitely in a capacitor; eventually it leaks off.

Insulation resistance (IR) is the resistance of the dielectric. High resistance results in low leakage current. This variable is inversely related to ambient temperature.

Capacitive reactance (X_C) of a capacitor is inversely related to the product of capacitance and frequency in accordance with:

$X_C = 0.159/f \times C$

where 0.159 is a conversion constant

X_C = capacitave reactance (ohms)

f = frequency (hertz)

C = capacitance (farads)

www.americanradiohistory.com

Power factor (PF) expresses the ratio of energy dissipated to the energy stored in a capacitor, as a percent. It typically exhibits a negative slope below room temperature and positive slope above it.

Equivalent series resistance (ESR), expressed in ohms, is the sum of all internal resistance values of a capacitor. These include lead resistance, terminal losses, and dissipation in the dielectric. ESR increases with frequency.

Impedance (Z) of a capacitor is the total opposition it offers to the flow of alternating current at a given frequency:

$$Z = \sqrt{X_C{}^2 + (ESR)^2}$$

where Z = impedance (ohms)
$X_C{}^2$ = capacitive reactance (ohms)
ESR = equivalent series resistance (ohms)

Capacitive impedance is inversely proportional to frequency and temperature; ideally, it equals capacitive reactance.

Dissipation factor (DF) of a capacitor is the ratio of energy dissipated to energy stored in the dielectric. DF is a figure of merit for the quality of a capacitor.

$$DF = ESR/X_C \times 100\%$$

Ideally capacitors have low values of DF over wide temperature ranges.

Q or *Quality factor* is the ratio of energy dissipated to energy stored, so it is the reciprocal of dissipation factor at low frequencies.

$$Q = 1/DF = X_C/ESR$$

The highest quality capacitors have high Q's.

Ripple current is the result of a periodic AC voltage wave superimposed on the DC voltage applied to the capacitor. Ripple current flowing through the ESR of a capacitor can generate heat, raising the temperature of the capacitor.

Volumetric efficiency is a measure of relative capacitance per unit volume. One capacitor has a higher volumetric efficiency than another capacitor of the same size (volumetric dimensions) if it is able to store more charge, or has a higher capacitance rating.

Capacitor applications

Capacitors have many different applications in electronic circuits:

- *Blocking*—limiting the flow of direct current or low frequency alternating current without significantly affecting the flow of high-frequency AC.
- *Bypassing*—providing a low-impedance path around a circuit component to permit the flow of alternating current
- *Coupling/decoupling*—coupling or decoupling alternating signals between circuits and systems.
- *Energy storage*—storing electric energy for later release to power a device or circuit.
- *Filtering*—removing the DC component from a signal.
- *Smoothing*—reducing the ripple on an input signal
- *Timing*—providing capacitance value in timing circuits.
- *Tuning*—providing capacitance value for tuning in a tank circuit.

Fixed capacitors

Figure 2 is a diagram showing how fixed capacitors are classified as *electrostatic* and *electrolytic*. Electrostatic capacitors are so named because an electrostatic charge is stored between opposing plates. They are named for the dielectrics between their plates. This can be air or a vacuum or such solid materials as plastic film, ceramic, mica, and glass.

Electrostatic capacitors are further classified by packaging method: leaded or non-leaded (chip); radial or axial leaded; molded, conformally coated, or dipped in an encapsulant, typically epoxy. A film capacitor can be further classified by the specification of its plastic film such as polyester or polycarbonate.

Electrolytic capacitors are made of metals, normally either aluminum or tantalum, that form extremely thin anodic oxide layers of high-dielectric constant and good electrical characteristics during electrolytic processing. These capacitors are classified by the metal from which their anodes are made—aluminum or tantalum—and capacitor configuration: wet foil, wet slug, or dry slug (solid electrolyte).

Film capacitors

Film capacitors are made with thin dielectric plastic films such as polyester (Mylar), polycarbonate, polystyrene and polypropylene that is 0.06 mil (1.5 micrometers) to over 0.8 mil (20 micrometers) thick. The electrodes of film capacitors can be metal foil (film/foil) or metal directly deposited on the film (metalized). Film/foil capacitors are made of dielectric film sandwiched between tin or alumi-

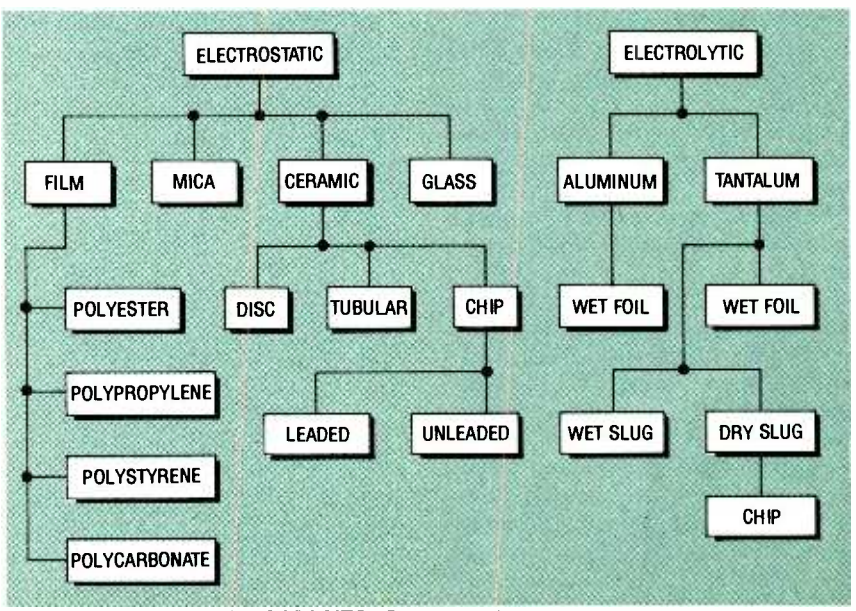

FIG. 2—POPULAR FIXED CAPACITORS are organized as electrostatic and electrolytic, and identified by their dielectric and package style.

www.americanradiohistory.com

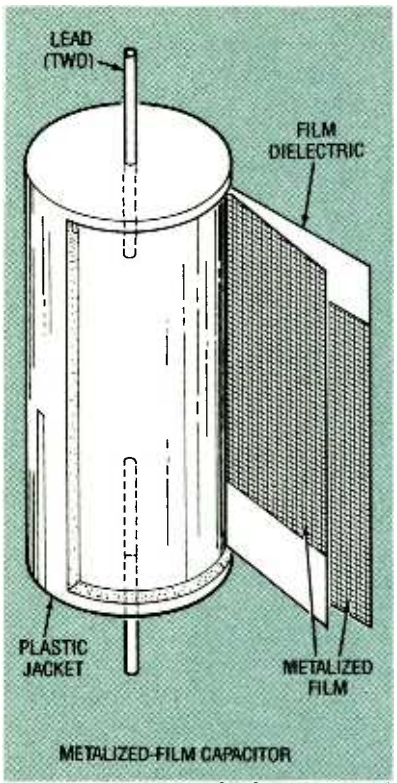

FIG. 3—VIEW OF PLASTIC-FILM capacitor shows how metalized-film dielectric (with leads connected) is rolled into a cylinder and jacketed with molded or conformally coated plastic.

num foil plates (about 0.25-mil thick). They are most widely specified for energy storage, pulse discharge, and arc suppression applications.

The plates of metalized capacitors are very thin vacuum-deposited layers of aluminum or zinc, which permits these capacitors to be smaller and lighter than film/foil capacitors with the same capacitance ratings. These capacitors can be made as shown in Fig. 3, or the metalized film can be cut into rectangles and stacked. The stacks are then leaded and molded in a protective encapsulant package.

Self-healing is a very important feature of metalized-film capacitors. A localized dielectric breakdown caused by a transient overvoltage will not necessarily cause capacitor failure because the metalized film around the fault evaporates without shorting the adjacent metalized plates. This response isolates the fault and effectively restores the electrical properties of the capacitor.

Both film/foil and metalized-film capacitors are made with axial or radial leads in a variety of case sizes. They can be hermetically sealed in tubular or rectangular metal cases, or encapsulated by molding or conformally coating with epoxy.

Film capacitors are most widely specified for capacitance values from 500 picofarads to 10 microfarads. (Refer to Table 2.) Their working voltages typically range from 50 volts DC to 630 volts DC—although they can have higher ratings. Capacitance tolerance is typically from ±1% to ±10%

Film dielectrics

The four most widely used film dielectrics are:

- *Polyester* (tradenamed Mylar) capacitors are the most popular general-purpose film capacitors. This film permits high volumetric efficiency, low leakage, and a moderate temperature coefficient. Some film/foil and metalized units can operate to 125°C at 50% of rated voltage. Metalized- polyester units can perform blocking, coupling, decoupling, bypass, and filtering.
- *Polycarbonate* capacitors have operating temperatures from -55°C to as high as +125°C with proper voltage derating. Capacitive tolererances can be as low as ±5%. This dielectric film offers high insulation resistance and stability.
- *Polystyrene* capacitors have characteristics that are similar to those of polypropylene, but they have lower volumetric efficiency. They have capacitive tolerances as low as 1%. Film/foil units are widely used in inductive-capacitive filters.
- *Polypropylene* capacitors have higher volumetric efficiency than polyester capacitors. Except for AC rating, their characteristics are similar to those made from polystyrene. They have tolerances as low as ±2%. These capacitors are specified where precision, reliability, and low losses are important: e.g. tuning, filtering, and timing.

Ceramic capacitors

There are three ceramic capacitor styles: single-layer disc, single-layer tubular, and monolithic multilayer. There are three principal classes of ceramic dielectric based on their *k* rating: Class I, II, and III. Low-*k* materials have linear characteristics, and their properties are independent of frequency over their normal range. They are suitable for resonant-circuit or filter

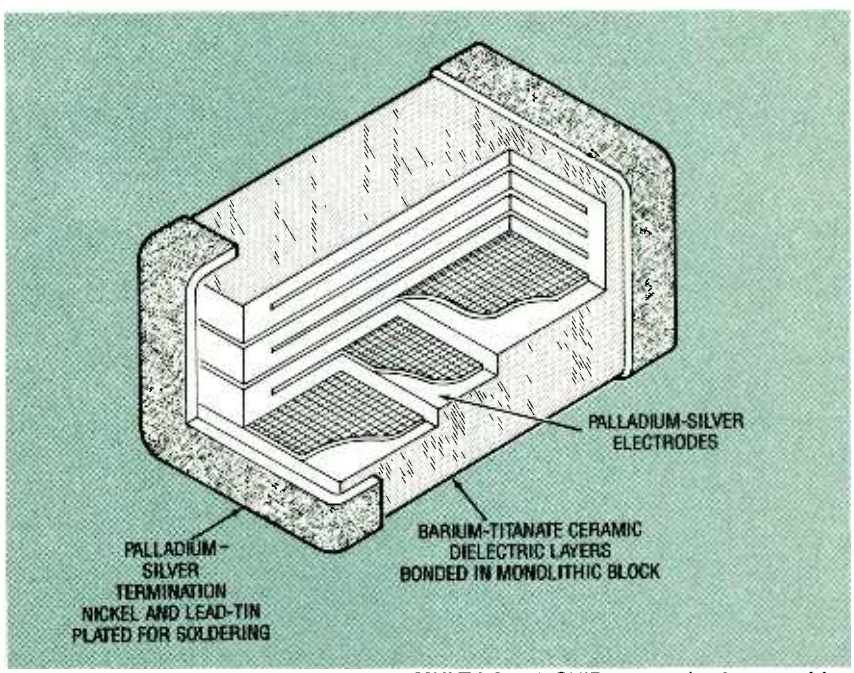
PALLADIUM-SILVER ELECTRODES
BARIUM-TITANATE CERAMIC DIELECTRIC LAYERS BONDED IN MONOLITHIC BLOCK
PALLADIUM-SILVER TERMINATION NICKEL AND LEAD-TIN PLATED FOR SOLDERING

FIG. 4—CUTAWAY VIEW OF A CERAMIC MULTILAYER CHIP capacitor shows noble-metal electrodes deposited on thin layers of ceramic dielectric which are then pressed and fired to form a monolithic unit.

www.americanradiohistory.com

characteristics. High-K ceramics have very high effective dielectric constants. They are suitable for coupling and decoupling applications.

- *Disc ceramic* capacitors are made by metalizing both surfaces of a thin low-k (Class III) ceramic disc with silver-based ink to form the electrodes, firing the disk, and soldering on radial leads. They are jacketed by dipping in phenolic resin or epoxy. These capacitors are being replaced by tubular ceramic units made of the same materials that save circuit board space and permit automatic parts placement.
- *Tubular ceramic* capacitors are made by coating the inner and outer surfaces of Class III ceramic tubes with silver-based thin-film ink, firing, and attaching leads to the tube before jacketing it by epoxy dipping.
- *Monolithic multilayer ceramic* (MLC) capacitors are made by screening thin-film, precious metal-based conductive ink on thin layers of "green" or unfired layers of higher k (Class II and III) ceramics. The screened layers are then stacked (up to 40 layers), compressed, and fired to form monolithic capacitors, as shown in Fig. 4.

If the MLC capacitor is to be a chip capacitor for a hybrid circuit or surface-mounting, conductive-metal terminations are plated on its ends, as shown in Fig. 4. The terminals of surface-mount chips are further plated with lead-tin alloy to improve the terminal-to-pad solder joints.

Demand for MLC chips has risen with the worldwide growth of surface mounting. Chip MLC's will withstand the molten- solder temperatures encountered in reflow and wave soldering. They are available in standard sizes to fit the grasping tools in automated pick and place machines. The most common sizes are 0.08 ×0.05 inch (0805), 0.125 × 0.063 inch (1206), and 0.05 ×0.225 inch (2225).

Cylindrical leadless capacitors are also made for surface mounting. These capacitors

TABLE 2
CHARACTERISTICS OF POPULAR FIXED CAPACITORS

Type	Capacitance Range	Working Voltage	Maximum Operating Temp. (C)	Tolerance (Percent)
Electrostatic				
Film				
Polyester (Mylar)				
Film/foil	0.001—1.0	80—200 VDC	+125*	±5—±10
Metalized	0.001—10.0	60—630 VDC	+125*	±5—±10
Polycarbonate				
Metalized	0.01—10	100—630 VDC	+125*	±5—±10
Polystyrene				
Film/foil	47 pF—0.039	63—630 VDC	+85	±1—±5
Polypropylene				
Film/foil	47 pF—0.022	63—630 VDC	+85	±2—±5
Metalized	0.001—3.3	250—100 VDC	+85	±5—±10
Ceramic				
Multilayer	10 pF—.56	200 VDC	+125	±5—±10
Disc	.75 pF—2.2	50—6 KVDC	+125	±5—±10
Mica	1 pF—0.1	50,000	+150	±.25—±5
Glass	10 pF—0.15	6000	+125	±1—±20
Electrolytic				
Aluminum	1.0—1 MEG	5—450	+105	−10—+100
Tantalum				
Wet slug	1.7—2400	6—630	+125	±5—±20
Wet foil	.12—3500	3−300	+125	±5—±20
Solid slug	0.0023—1000	6—100	+125	+5—±20

* With derating

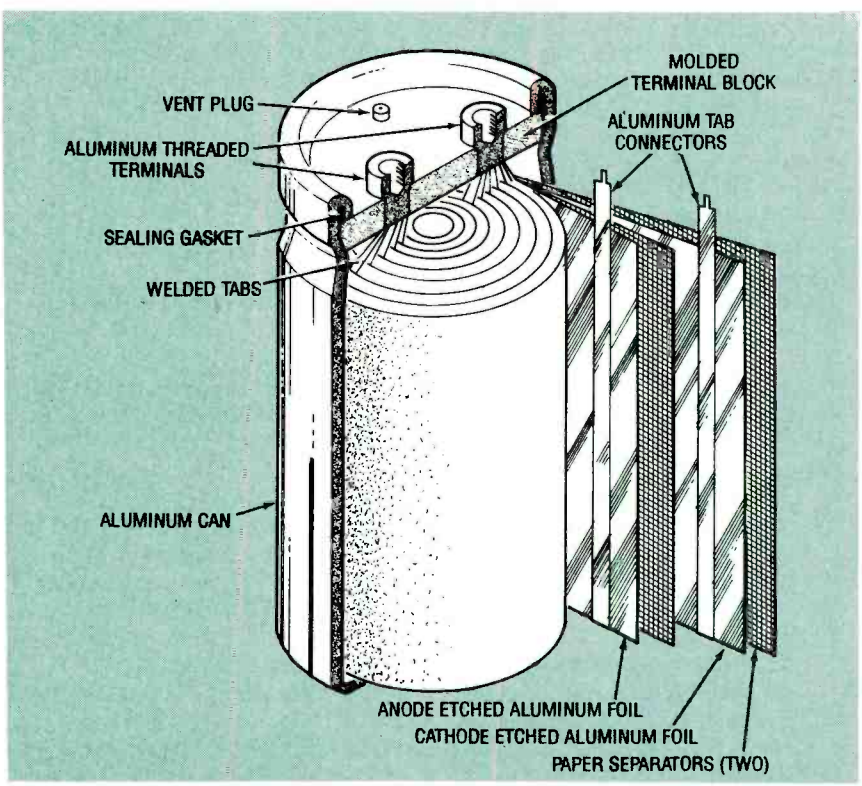

FIG. 5—VIEW OF AN ALUMINUM ELECTROLYTIC CAPACITOR shows how the cathode (porous paper spacer filled with liquid electrolyte) is sandwiched between the oxidized aluminum anode foil and cathode connection foil, rolled into cylinder,and then sealed in an aluminum can.

www.americanradiohistory.com

have metalized-band contacts on the ends of their epoxy-coated bodies for soldering to lands of surface-mount circuit boards.

For conventional through-hole mounting, axial or radial leads are attached, and the chip is jacketed by dipping or molding in epoxy. MLC capacitors are specified for bypassing noise to ground, timing, and frequency selection.

Ceramic dielectrics

Ceramic dielectric materials are classified by dielectric constant *k* as Class I, Class II and Class III:

- *Class I* dielectrics are made by mixing magnesium titanate (for a positive temperature coefficient) with calcium titanate (for a negative coefficient) to form a dielectric material with low *k* values, and properties essentially independent of frequency. They exhibit ultrastable temperature coefficients of ±30 ppm/°C over the temperature range of -55° to +125°C. Class I includes NPO (negative, positive, zero), also known as COG and BY.
- *Class II* dielectrics are high-*k* materials (called ferroelectrics) based on barium titanate. With the addition of barium stanate, barium zirconate, or magnesium titanate, their dielectric constants can be lowered from values as high as 8000 for increased temperature stability. These dielectrics include general purpose X7R (BX) and Z5U (BZ).
- *Class III* dielectrics were developed primarily for ceramic disc capacitors because they permit high volumetric efficiency. But this introduces a trade-off between high leakage resistance and low dissipation factor. Class III capacitors have low working voltages.

Other electrostatic capacitors

The dielectric in a *mica* capacitor is mica, a natural mineral that is chemically inert and very stable. The capacitor is generally made as a "sandwich" of alternating layers of tin-lead foil plates and mica. These capacitors can operate at temperature up to +150°C. Silvered mica capacitors offer greater mechanical stability and more uniform characteristics. They are made by screening and firing a thin layer of silver on the surface of the mica to form the plates.

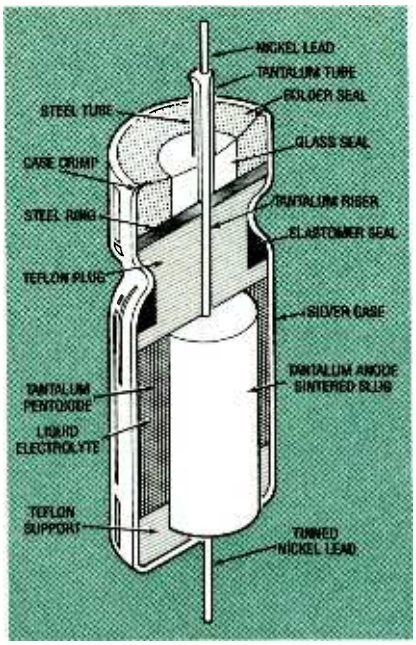

FIG. 6—CUTAWAY VIEW OF WET-SLUG tantalum capacitor shows tantalum slug filled with wet-electrolyte sealed in a silver case.

Glass capacitors are made by stacking alternate layers of thin glass dielectric in a sandwich structure similar to that of the mica capacitor. They are specified where temperature stability is a requirement.

Electrolytic capacitors

The dielectrics of aluminum and tantalum electrolytic capacitors are oxides formed by electrochemical reaction with those metals. There are three styles of electrolytic capacitor: wet foil, wet slug, and dry or solid slug. Aluminum electrolytic capacitors are wet foil units, but tantalum capacitors are also available as wet-slug and solid slug units.They can be *polarized* or *nonpolarized*.

All electrolytic capacitors exhibit high capacitance per unit volume (high volumetric efficiency). An aluminum electrolytic capacitor can store four, five or more times the charge of an equivalent-size film capacitor, and a tantalum capacitor can store three times as much charge as an equivalent aluminum capacitor.

However, aluminum electrolytic capacitors have higher DC leakage and lower insulation resistance than electrostatic capacitors. Moreover, they have higher power losses because of their higher equivalent series resistance (ESR).

The anodes of aluminum electrolytic capacitors are made from high-purity aluminum foil that has been electrochemically etched to increase its effective surface area. A thin aluminum-oxide-dielectric layer, about 0.01 micron, is then grown on the etched foil in another electrochemical process. The enlarged surface area of the etched foil provides a far larger dielectric surface than would be possible with unetched foil.

A porous paper spacer filled with a liquid electrolyte is sandwiched between the etched and oxidized anode foil and another aluminum cathode foil. The liquid electrolyte is the actual cathode, but the cathode foil is in contact with the liquid electrolyte and is needed to complete the electrical circuit.

After attaching a series of connecting tabs to the foils, the "sandwich" is rolled, as shown in Fig. 5, and inserted in an alu-

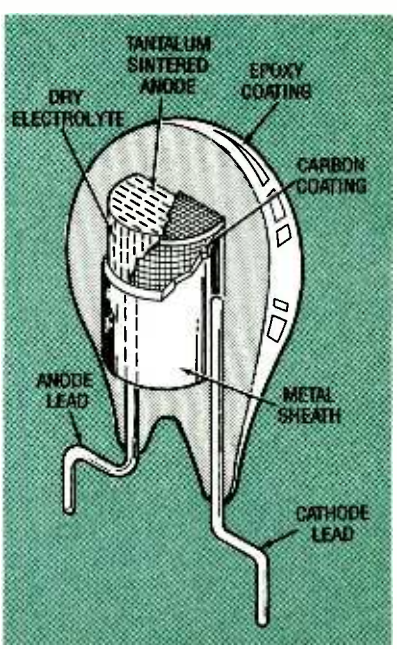

FIG. 7—CUTAWAY VIEW OF A SOLID tantalum capacitor jacketed by dipping in epoxy.

www.americanradiohistory.com

minum can, which is then sealed. However, the sealed can has an overpressure vent.

Direct current must flow in only one direction in a polarized electrolytic capacitor. Even short-term current reversal could destroy the oxide dielectric and short-circuit the capacitor. A "+" mark on the case identifies its positive terminal.

Aluminum electrolytic capacitors are made with radial or axial leads, and some styles for switchmode power supplies have spring-metal terminals that snap into circuit board holes. An external plastic sleeve permits off-ground applications for the capacitor.

Nonpolarized aluminum electrolytic caps are essentially two polarized capacitors back-to-back with their cathode terminals connected. The anode terminals make the external circuit connection, while the cathode terminals are isolated by an insulator. Both foils are anodized to form oxide barriers, and they share a common electrolyte-filled porous spacer.

A nonpolarized capacitor has half the capacitance of a comparably sized polarized capacitor with the same voltage rating. Although not as efficient as polarized capacitors, the nonpolarized units are used for AC motor starting and other AC control applications.

Tantalum capacitors

Tantalum electrolytic capacitors are available in three forms: wet-foil, wet slug, and dry slug. Wet-foil tantalum capacitors are made in about the same way as aluminum electolytics. As a group, tantalum capacitors exhibit higher volumetric efficiency, more stable characteristics, higher operating temperature ranges, and longer shelf lives than aluminum capacitors. However, they cost more and have lower voltage ratings.

Both wet and dry slug tantalums are made from porous pellets of tantalum. The anode slug is formed by pressing tantalum powder and a binder in a mold, and firing it in a vacuum furnace (*sintering*) to bond the powder and drive off the binder.

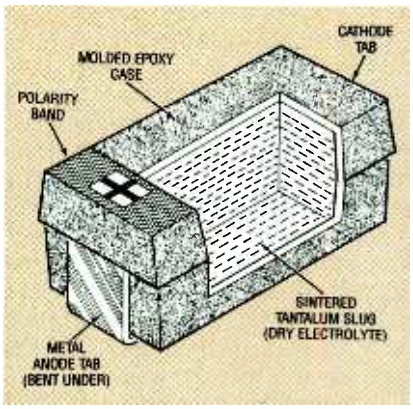

FIG. 8—CUTAWAY VIEW OF A SOLID tantalum capacitor chip for surface mounting applications.

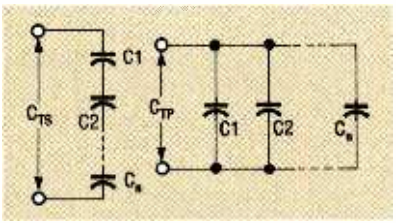

FIG. 9—CONNECTING CAPACITORS in series yields a total capacitance that is less than that of the lowest-value unit (*a*), but connecting them in parallel yields a total capacitance equal to the sum of all unit values.

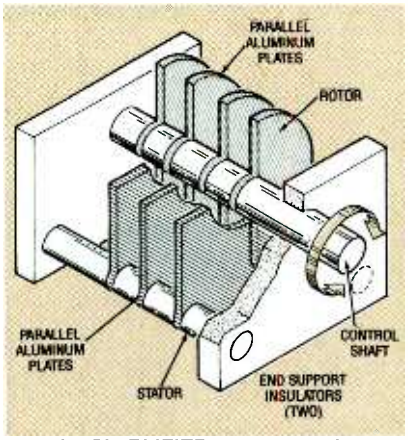

FIG. 10—SIMPLIFIED DRAWING of a tuning capacitor shows a concept that is used in many variable capacitors.

The tantalum oxide dielectric is electrochemically formed in the porous pellet.

Figure 6 is a cutaway view of a wet-slug tantalum capacitor with an acid electrolyte. Its volumetric efficiency about three times that of a comparably sized foil unit. Moreover, wet-foil tantalums are the most reliable of all capacitors.

The high cost of wet-foil and wet-slug tantalums makes them too expensive for most consumer and industrial applications. However, those high-reliability capacitors are widely specified for military electronics and avionics. Military specifications MIL-C-3965 and MIL-C-39006 govern the procurement of military-style wet-foil and solid-slug units.

The solid-anode or dry-slug unit, shown in Fig. 7, is the most popular and economical tantalum capacitor. It has a thin film of manganese dioxide chemically deposited on its tantalum dioxide dielectric to act as a second electrode. Solid-slug capacitors can be sealed in metal cases, or protected by dipping in epoxy as shown in Fig. 7. The solid-slug units have the longest life and lowest leakage of any tantalum caps. Chip capacitors for surface mounting, as shown in Fig. 8, are made by the same process.

Capacitor identification.

Today the capacitor's nominal value (and sometimes its tolerance) are printed on its body where space permits. Values such as 47 and 68 are typically in microfarads, while values such as 120 or 4700 are usually in picofarads. A capacitor might also be marked with its working voltage: for example, 63 V or 100 V.

Some capacitors are still marked with colored bands based on the EIA system used for identifying resistors. The colors of the bands are read from left to right. A black band represents zero, brown represents one, and red, orange, yellow, green, blue, and violet represent the digits two to seven, in that order. Grey represents eight, and white represents nine. As in resistor coding, a gold band denotes a capacitive tolerance of 5%, while a silver band denotes 10%.

You might encounter capacitors with obsolete coding schemes in old radios or TV's or at surplus sales. Some of those codes are based on colored dots, spots or "hashmarks." It is wise to consult a radio engineering handbook or data reference book published before 1970 if

www.americanradiohistory.com

you want to find out how to interpret those codes if you plan to use them in your circuits and are in doubt about their ratings.

Connecting capacitors

Figure 9 illustrates capacitors connected in series and parallel. The formula for calculating the effective value of two capacitors in series is:

$C_{TS} = C1 \times C2/C1 + C2$

For two or more capacitors in series it is:

$C_{TS} = 1/1/C1 + 1/C2 + 1/C3 + 1/C_n$

For capacitors in parallel the formula is:

$X_{TP} = C1 + C2 + C3 + C_n$

Variable capacitors

For many years the most prominent variable capacitors were those used to tune radio receivers, transmitters, and oscillators. However, in the latest transistorized equipment they have been largely superseded by *varactors* or voltage variable capacitors. These are silicon or gallium arsenide PN junction diodes that make use of the variation of junction capacitance with reverse bias. Nevertheless, the design concept embodied in the tuning capacitor lives on in a wide range of miniature, PC board-mounted variable capacitors for many different tuning applications.

Figure 10 is a simplified sketch of an air-dielectric tuning capacitor. Its capacitance value can be changed by rotating its control shaft so that the movable set of metal plates (*rotor*) meshes in different positions with respect to the fixed set (*stator*). Its capacitance value is greatest when the rotor is fully meshed with the stator.

The rotor plates of tuning capacitors can be shaped so that, with shaft rotation, capacitance variation is linear or nonlinear. For example, it might follow a nonlinear logarithmic or square law function. Two or more tuning capacitors can be ganged together so that they vary in unison, simultaneously tuning separate circuits to different frequencies.

Trimmer capacitors are "set and forget" variable capacitors made for infrequent adjustment. Many different types are available for commercial and industrial applications. *Vane* types are miniaturized versions of the tuning capacitor shown in Fig. 10, except that layers of solid dielectric, typically plastic, are inserted between the rotor and stator plates.

Vane-type trimmers with body diameters of less than a half inch are made for PC-board mounting. They have plastic cases and dielectrics of polypropylene, polyethylene, polycarbonate, or PTFE films. These trimmers are made for screwdriver and/or key adjustment.

There are also simpler trimmer capacitors that permit more limited capacitance variation for high-frequency tuning applications. Ω

EVERY ACTIVE KIT CONTAINS:
- All components including printed circuit board and solder
- Complete assembly instructions and schematic diagrams

A001..1-24VDC Regulated Power Supply..$21.95
A002..16 LED Light Chaser..$19.95
A003..2000 Watt Colour Light Organ..$22.95
A004..2 Channel Audio LED Power Meter..$16.95
A005..Variable Strobe Light..$16.95
A008..1 MHz Function Generator..$33.95
A009..Stepper Motor Controller..$29.95
A010..8 Watt Audio Amplifier..$21.95
A011..Electronic Siren..$21.95
A012..Power Supply +12V@2.5A; +15V,-15V@1A..$25.95
A013..Digital Capacitance Meter..$38.95
A014..Digital Volt Meter..$23.95
A015..12 Volt Fluorescent Ballast..$12.95
A016..9 Volt Digital Dice..$16.95
A017..Battery Level Monitor..$12.95
A018..LED Light Sweeping Star..$16.95
A019..Remote InfraRed Switch..$16.95
A020..Digital Timer..$29.95
A021..Stepper Motor Controller #2..$33.95
A022..8 Channel 120V Light Chaser..$20.95
A023..Electronics 101..$38.95
A024..Logic Probe..$19.95
A025..Fire Ball..$29.95
A026..Bug Off..$8.95
A027..100W High Power Audio Amplifier..$42.95
A028..Low Voltage Strobe..$16.95
A029..8 Channel Stepper Motor Driver..$50.95
A030..Unreg. Power Supply +/- 45VDC..$59.95
A031..Speaker Switch Box
A032..10-30V, 3A Reg. Power Supply
A033..Resistor Switch

MANY MORE TO COME
CALL 1-800-465-5487

All kits quoted in U.S. dollars. No C.O.D. orders please.

ACTIVE KITS — 345 QUEEN ST. W., TORONTO, ONT. M5V 2A4

CIRCLE 188 ON FREE INFORMATION CARD

GET THE LATEST ADVANCES IN ELECTRONICS

WITH A SUBSCRIPTION TO

Electronics NOW
Radio Electronics Combined with Electronics NOW

ENJOY THE WORLD OF ELECTRONICS EACH MONTH!

Electronics Now looks to the future and shows you what new video, audio and computer products are on the horizon. What's more you'll find helpful, monthly departments such as Video News, Equipment Reports, Hardware Hacker, Audio Update, Drawing Board, Computer Connections, New Products, and more. All designed to give you instruction, tips, and fun.

SUBSCRIBE TODAY

Just fill out the order card in this magazine and mail it in today.

FOR FASTER SERVICE CALL TODAY

1-800-999-7139 7RC35

www.americanradiohistory.com